FORMATION OF SPARKS FROM ABRASIVE WATERJET CUTTING AND THEIR EFFECTS ON CONDENSED EXPLOSIVES

A continuation of Alliant Techsystem's research on waterjet cutting of explosive

Paul L. Miller
Engineering Fellow

Alliant Techsystems Inc.
600 Second Street Northeast
Hopkins, MN 55343

ABSTRACT

Sparks have been frequently noted in the process of abrasive waterjet cutting of explosive ordnance. These sparks have not, however, caused an ignition event in the nearly 200,000 items cut to date. Research performed into the mechanisms of spark formation, explosive initiation, and waterjet cutting process has shown that these sparks are benign when certain parameters are controlled.

Background

Alliant Techsystems has researched the use of high-pressure abrasive waterjets on the sectioning of high-explosive projectiles since 1990 in support of our demilitarization processes. The high pressure fluid testing has used fluid pressures of up to 1 gigapascal (147,000 psi) impacting both PETN and TNT without explosion. Testing performed by Alliant Techsystems with abrasives aspirated into the fluid stream, known as abrasive waterjets, have cut almost 200,000 projectiles containing aluminized high-explosive. The abrasive waterjet tests were conducted using water pressures of approximately 300 megapascals (45,000 psi) and were successfully performed without event.

Observations during the abrasive waterjet cutting tests showed definitive spark formation presumably due to the action of the 80 mesh garnet abrasive on the ASI 4130 steel projectiles. Although sparks were observed, the tests were continued without any other abnormality despite the presence of RDX, HMX and powdered aluminum from the portion of explosive sectioned by the jet stream during the cutting of the projectile. The sparks observed when cutting inert metal samples were in the order of less than five per second and the particle sizes were calculated as being less than 100 microns in length, based on SEM photographs of captured materials. Since the presence of sparks has been seen as being a primary cause of ignition and subsequent detonation of propellants and explosives, abrasive waterjet cutting should, logically, be a hazardous process.

However, empirical testing of 200,000 projectiles without an event has demonstrated that there is a serious difference between conventional wisdom and actual ignition mechanisms.

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Conventional wisdom about safety is occasionally applied in general terms to prevent confusing people with too many specifics. This generalization is like a "false positive" in experimental statistics. While it is highly desirable to "err on the side of safety," a more serious situation occurs when conventional wisdom has not taken into account the underlying scientific basis of the physical process.

Since the presence of sparks during the abrasive waterjet cutting of the explosive projectiles was demonstrated to be safe at the 99.9995% point estimate, finding an explanation on the physical processes why it was safe became critical. A literature search identified numerous articles about electric spark initiation of condensed explosives, but very little information on non-electric spark effects on explosive. This paper is a compilation of data from existing articles that tries to clarify why no initiation of explosive materials occurs during abrasive waterjet cutting and to identify some ignition misconceptions.

Results of Literature Searches

The results of the literature searches identified a number of surprising findings. First of all, there are three distinctively different types of sparks[1]. Sparks are identified as being friction sparks, impact sparks or electrical sparks. Friction and impact sparks are the result of two hard materials respectively abrading or impacting each other and are similar in nature. Electrical sparks are the result of a discharge between two items having different electrical potential. Although these three sparks may look identical, they perform very differently from each other. Electrical spark ignition has a well-developed methodology[2] and repeatable results can be achieved when electrode size, shape and material are described along with the spark duration and gap. For these reasons most of the sensitivity tests on energetic materials are based on electric spark initiation tests.

The energy levels required for electric and impact sparks to ignite materials, however, is significantly different. The energy to ignite 50% of the tests (E_{50}) for hydrogen/air using electric sparks[3] is on the order of 30 mJ, while impact sparks[4] caused by two steel plates takes a phenomenal 497 Joules to ignite the hydrogen/air mixture. It should be obvious that there must be significantly different initiation mechanisms in these two events. In Alliant

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[1]Berstein, Harold and Yound, George; Sparking Characteristics and Safety Hazards of Metallic Materials; NAVORD RPT 5205; 8 Apr. 1957; AD 127 905.

[2]Roux, Michel, Auzanneau, Max and Brassy, Claude; "Electric Spark and ESD Sensitivity of Reactive Solids (Primary or Secondary Explosive, Propellant, Pyrotechnics) Part One: Experimental Results and Reflection Factors for Sensitivity Test Optimization;" Propellants, Explosives, Pyrotechnics; Vol. 18, 1993; pg. 317.

[3]Guoxiang, Li and Changying Wang; "Comprehensive Study on Electric Spark Sensitivity of Ignitable Gases and Explosive Powders;" Journal of Electrostatics, Vol. 11, 1982; pg. 329.

[4]Titman, H. and Wynn, A.; The Ignition of Explosive Gas Mixtures by Friction; Safety in Mines Research Establishment, Ministry of Fuel and Power (UK); Research Report No. 95, July 1954; pg. 12. (The reader should be advised that the impact tests actually identified only the 15% initiation level at 497 Joules.)

Techsystems' abrasive waterjet cutting, the generation of sparks appears to be from abrasive impact on steel when using garnet abrasives. In similar tests by the British Hydromechanics Research Association,[5] abrasive waterjets did not ignite controlled hydrogen/air mixtures in their test chambers. The failure of hydrogen to ignite in either of these abrasive waterjet test sequences is understandable if we accept that impact sparks require significantly higher energies to ignite materials than do electric sparks.

Two major reasons may exist for the difference in energies required to ignite materials by electric or impact sparks. First, electric sparks appear to be much more complex than just generating a "hot spot" that ignites the materials through thermal processes. Tests performed with silver azide[6] showed that the passage of electrical current through the explosive of insufficient energy for ignition was actually changing the composition and sensitivity of the explosive. The electric charge may be interacting with explosive as a dielectric material. Other tests have shown that sparks from quartz will ignite materials, not based on the sparks thermal energy, but on the triboelectric discharge[7] from the quartz being struck.

The second main reason for the difference in energies required to ignite materials with impact sparks is that thermal ignition of materials is a physically complex task that may require additional energy. Studies have shown that the minimum thermal ignition kernel (initial spheroid of ignited material) for a hydrogen/air mixture[8] is approximately 2 mm. Several studies[9] [10] [11] that have looked at hot particle ignition of flammable gases suggest that for a given ignitable material the temperature necessary for a given probability of ignition is inversely proportional to the heated particle's surface area. The studies show that the temperature required for hot particles to ignite hydrogen/air goes up rapidly for particles less than 4 mm in diameter. For 2 mm diameter, metal particles, the temperature required to give

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[5] Elvin, R. and Fairhurst, R.; "Abrasive Jet Cutting in Flammable Atmospheres - Potential Applications for Mining;" Automation for Mineral Resource Development, Queensland, Australia, 1985; pg. 26.

[6] Roux, op cit; pg. 323.

[7] Wynn, A.; The Ignition of Firedamp by Friction; Safety in Mines Research Establishment, Ministry of Fuel and Power (UK); Research Report No. 42, July 1952; pg. 13.

[8] Dixon-Lewis, G.; "Effect of Core Size on Ignition Energy by Localized Sources;" Combustion and Flame, Vol. 33 1978; pg. 320.

[9] Cutler, D. P.; "The Ignition of Gases by Rapidly Heated Surfaces;" Combustion and Flame; Vol. 22, 1974; pg. 105-109.

[10] Cutler, D.P.; "Further Studies of the Ignition of Gases by Transiently Heated Surfaces;" Combustion and Flame; Vol. 33, 1978; pg. 85-91.

[11] Silver, Robert; "The Ignition of Gaseous Mixtures by Hot Particles;" Phil. Mag. S. Vol. 23, No. 156. Suppl. April 1937; pg. 647.

the 50% ignition probability[12] in hydrogen/air is 930º C. (Hydrogen's ignition temperature[13] is normally given as 500º C.)

Additional problems for either electric or thermal ignition of materials arise when high humidity or water is present. At humidities greater than 80%, the electrical energy required for ignition goes asymptotic as the spark energy is rapidly dissipated[14] by the water vapor. With thermal sparks, the thermal energy of the spark can easily be dissipated[15] by the quenching action of the water[16].

Given these basic events, the impact sparks from abrasive waterjet cutting are at a significant disadvantage to ignite materials. First, the particles from abrasive waterjet cutting, technically known as swarf, are very small compared with the particles sizes required, 100 µm maximum versus 2 mm. The temperature of the swarf cannot have exceeded their melting temperature since they do not show melting. Based on the melting temperature of steel being about 1400º C, this would be the logical limit to particle temperature. Extrapolating from the published[17] graphs, the temperature of the swarf is below that required for the ignition of hydrogen, let alone less reactive solid materials. Finally, the waterjet cutting process uses high-pressure water that not only drenches the parts being cut, but also provides an intense mist in the local cutting area. Any one of these processes is sufficient to prevent ignition of flammable materials from the few sparks generated by the abrasive waterjet cutting process. With the combination of all three processes, the probability of ignition is so low as to agree with actual experimental data.

WARNING

There does, however, appear to be sufficient concern in the literature regarding the specialized triboelectric hazards with quartz-bearing materials to preclude using any quartz-bearing materials as abrasives in waterjet cutting until specific testing is performed.

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[12] Silver; ibid.

[13] National Fire Protection Association, Fire Protection Guide on Hazardous Materials, 8th ed., 1984; Table 325M-59.

[14] Roux; op cit. pg. 321.

[15] Cybulski, W.; "Investigations on the Effect of a Water Mist and a Cloud of Stone Dust on the Ignition and Development of an Explosion of Firedamp;" Selected Translations on Explosives; U.S. Dept. of Interior; TT 63-11384. pg. 230.

[16] Mitani, Tohru; "A Flame Inhibition Theory by Inert Dust and Spray;" Combustion and Flame; Vol. 43, 1981; pg. 247.

[17] Silver; op cit. pg. 647.

Conclusions

Abrasive waterjet cutting produces some sparks from the impact of abrasive grains against hard objects such as the steel projectiles. These sparks are small particles in the order of 100 μm and they do not appear to have melted. Published literature supports the premise that these sparks are too small and have insufficient energy to ignite even highly flammable mixtures of hydrogen in air. In addition, the presence of water mist from the high-pressure waterjet seriously interferes with the ignition process. The non-ignitability of flammable materials by sparks from abrasive waterjet cutting agrees with the test data on both explosives and hydrogen/air gas.